Chemical Vapor Composite Silicon Carbide for Space Telescopes (Postprint)

Clifford Tanaka Kyle Webb

18 September 2006

Conference Proceedings

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14. ABSTRACT

The Purpose of this figure study was to demonstrate the optical figure and opto-mechanical performance capabilities for Trex's CVC SiC material. In the course of this activity a plano mirror was designed, fabricated, polished, and analyzed using interferometry tools and methods. The opto-mechanical and interferometric performance results are presented and analyzed in this report.

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Chemical Vapor Composite Silicon Carbide for Space Telescopes

AFRL Phase 2 SBIR

Clifford T. Tanaka / Kyle Webb

Trex Enterprises Corporation

HAWAIIAN OPERATIONS

MARRINA OPERATIONS

MARRINA OPERATIONS

Work supported by AFRL/DE

Thanks to:

- General Optics for optical metrology.
- 3D-Engineering Corp. for Finite Element Analysis.
- ATA Engineering Corp. for modal testing.
- Ormond, LLC for water jet milling.

Chemical Vapor Composite Silicon Carbide for Space Telescopes Overview

Goal: Produce a 750mm aperture CVC SiC mirror for the Advanced Relay Mirror System (ARMS)

Tasks

- 150mm CVC SiC Plano Mirror Figure Study
- Demonstrate fabrication of a stiff, high quality lightweighted mirror
- Compare modeled FEA modal performance vs. experimental measurements
- Evaluation of HEL coatings on CVC SiC coupons
- 750 mm CVC SiC mirror design & fabrication

Status:

- 150 cm CVC SiC Mirror analysis completed.
- HEL coating evaluation underway.
- 750 mm CVC SiC mirror design completed. Fabrication in 2007.



Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror Figure Study

- figure and opto-mechanical performance capabilities for Trex's CVC The purpose of this figure study was to demonstrate the optical SiC material.
- fabricated, polished, and analyzed using interferometry tools and In the course of this activity a plano mirror was designed, methods.
- The opto-mechanical and interferometric performance results are presented and analyzed in this report.

Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror

The following specifications were established to bench mark the optical and opto-mechanical performance in this effort:

Surface Figure:

Plano surface: 150mm outside diameter with a 95% clear aperture

• Peak to Valley reflected wave front error: $< \lambda/10$ at 632.8 nm

Surface Roughness: < 20 Å rms.

- Areal Density: </= 10 kg/m²

Modal Frequency Specification: >/= 1500 Hz in free-state

Ultra-Light-Weight, Open Back, Iso-Grid Mechanical Configuration: </= 200 grams

Design Approach:

- formulate an aggressive opto-mechanical design that would test the limits of the CVC SiC material as it is applied to challenging Finite Element Analysis (FEA) tools were used extensively to optical figure polishing processes.
- Sensitivities associate with self-weight-sag and print-through or quilting were anticipated to be revealed and studied.

Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror

150mm Mirror Detailed Design (sheet 1 of 2)



- APPLICABLE STANDARDS (SPECIFICATIONS)
 AN ASKIENTA SWAIPPA (DIMENSIONS AND TOLERANDES)
 B) 49-20-ESCOP (LATEST REVISION) DRAWING INTERPRETATION
- MATERIAL TREY DVC 5 C
- WEDGE < 1 ARC MITIUTE
- CHAMPER ALL EDGES TO 0.35 ±0,10 × 45 ±10"
- CLEAR APERTURE MIN 95% OF OD

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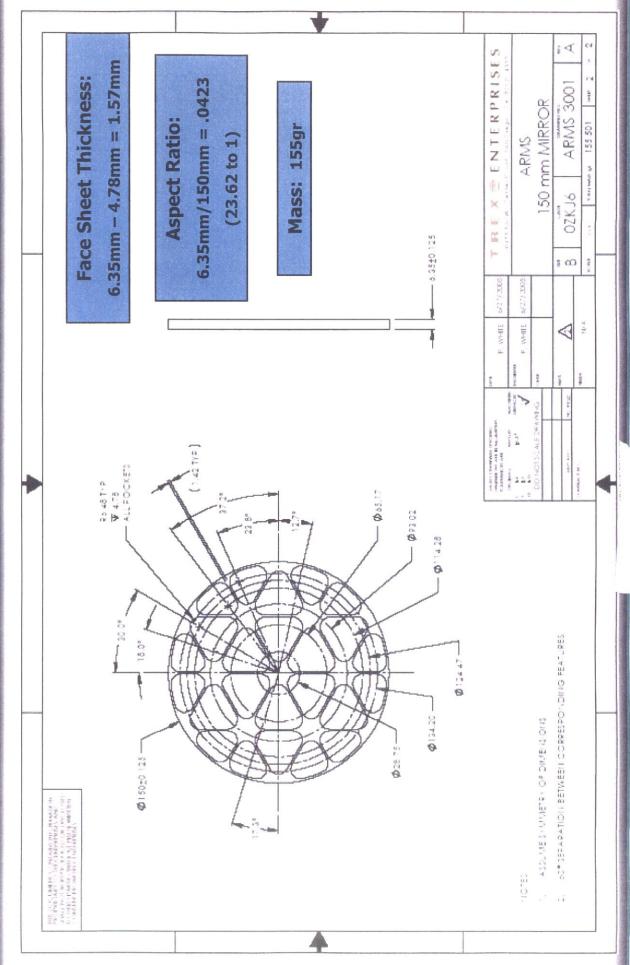
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Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm Mirror Detailed Design (sheet 2 of 2) 150mm CVC SiC Plano Mirror



HAWALIAN OPERATIONS

Horizontal:

- Three Point Supported at Iso-Grid Nodes
- Supported on Tissue Paper
- Supported at center Iso-grid Node
- Three Point support at Mirror Edge

Vertical:

- Edge mounted on a V block
- Edge mounted on a V block and rotated from original measured position.
- Edge mounted on a V block and rotated again from the last measured position.

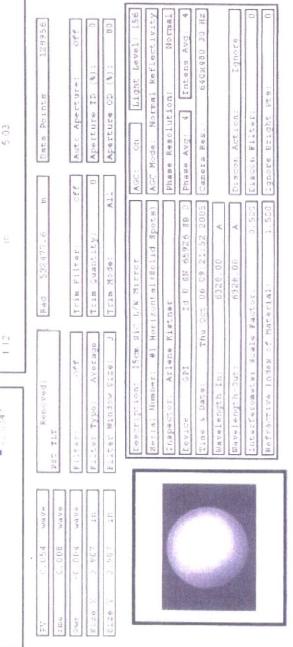
Chemical Vapor Composite Silicon Carbide for Space Telescopes Horizontal, Three Point Support at Iso-Grid Nodes 150mm CVC SiC Plano Mirror

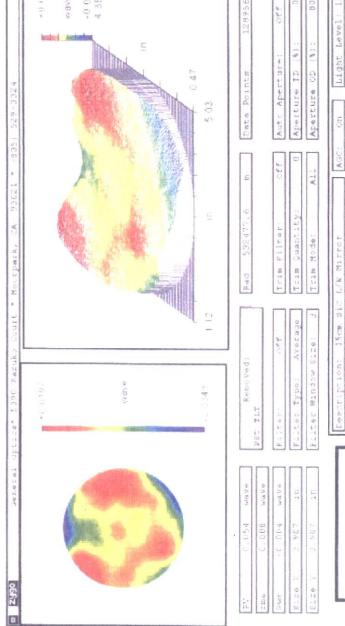
Interferometer Performance:

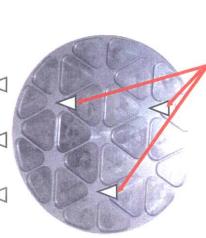
- pv 0.054 waves (λ/19)
- rms0.008 waves (λ/125)
- Pwr -0.004 waves

Measurement Orientation:

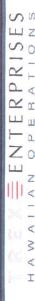
- Horizontal (flat on optical table)
- Mirror supported from point contacts on 3 isogrid nodes
- Produces best results on interferogram for this mounting orientation.







Three point support on iso-grid nodes



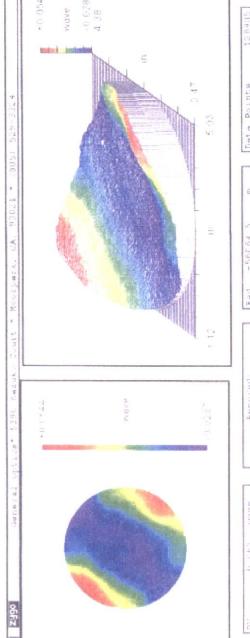
Chemical Vapor Composite Silicon Carbide for Space Telescopes Horizontal, Mounted on Tissue Paper 150mm CVC SiC Plano Mirror

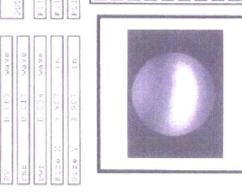
Interferometer Performance:

- pv 0.083 waves (2/12)
- Rms 0.017 waves (λ/59)
- Pwr 0.034 waves

Measurement Orientation:

- Horizontal (flat on optical table)
- Mirror supported with issue paper only.
- chip shape interferogram. Produces classic potato





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Tissue Paper Support



Chemical Vapor Composite Silicon Carbide for Space Telescop Horizontal Mount, Single Flat Contact Point at Center 150mm CVC SiC Plano Mirror

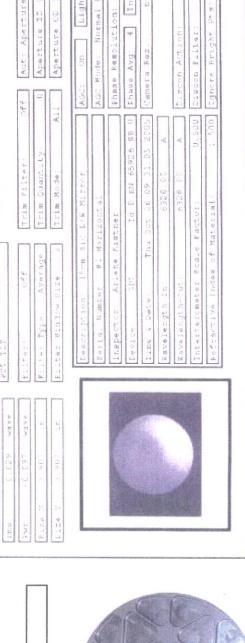
Interferometer

Performance:

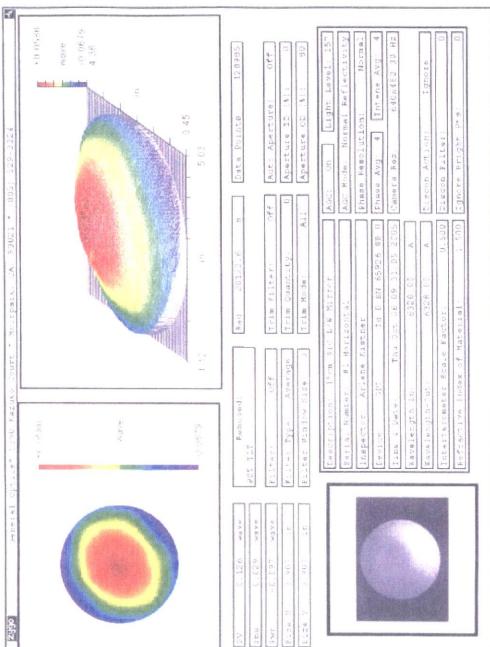
- pv 0.126 waves (λ/8)
- rms0.029 waves (λ/34)
- Pwr -0.097 waves

Measurement Orientation:

- Horizontal (flat on optical
- center iso-grid node flat o Mirror supported at the the back side only.
- Produces a convex shape as seen in the interferogram.







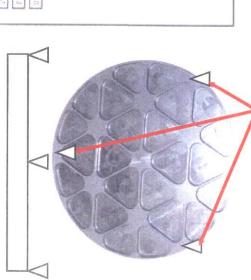
Chemical Vapor Composite Silicon Carbide for Space Telescopes Horizontal Mount, Three Point Support at Edge 150mm CVC SiC Plano Mirror

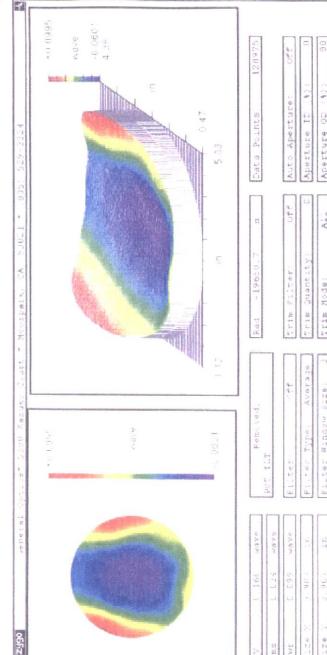
Interferometer Performance:

- pv 0.160 waves (λ/6)
- rms 0.034 waves (λ/29)
- Pwr 0.099 waves

Measurement Orientation:

- Horizontal (flat on optical table)
- Mirror supported with 3 point contacts at perimeter edge
- Produces lifted edge or concave profile on interferogram.





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Three point edge support configuration

Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror Vertical Mount, V-Block



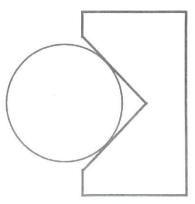
Interferometer

Performance:

- pv 0.064 waves (λ/16)
- rms0.010 waves (λ/100)
- 0.003 waves PWr

Measurement Orientation:

- Vertical (V-Block support)
- V-Block oriented in norma configuration as viewed ir interferograms.
 - Produces best results on interferogram for this mounting orientation.



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General Optics		

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	5.715

Average

Auto Aperture:

Data Points

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AGC: On	AGC Mode:	Phase Resolution:	Phase Avg:	Camera Res.		Discon Action	Discon Filter	Ignore Bright
Description: 15cm SiC L/W Mirror	Serial Number: #1	Inspector: Arlene Kistner	Device: Mark GPI Id U SN 3355 SB U	Time & Date: Thu Oct 06 08:19:34 2005	Wavelength-In: 6328.00 A	Wavelength-Out: 6328.00 A	Interferometer Scale Factor: 0.500	Refractive Index of Material: 1.500



Chemical Vapor Composite Silicon Carbide for Space Telescope Vertical Mount, V-Block (rotated) 150mm CVC SiC Plano Mirror



Interferometer

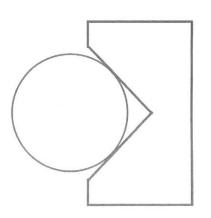
Performance:

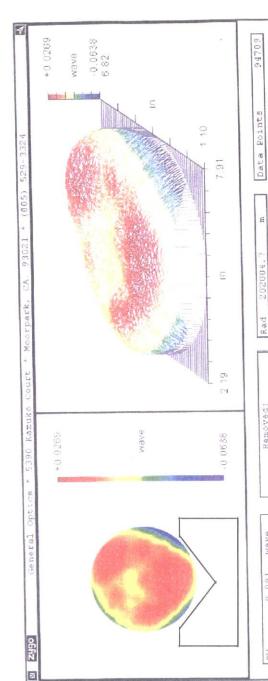
- pv 0.091 waves (λ/11)
- rms0.013 waves (\(\lambda/77\))
- waves PWr

-0.021

Measurement Orientation:

- Vertical (V-Block support)
- V-Block oriented in normal configuration as viewed in interferograms.
 - Rotated from previous position.





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Auto Aperture:

Removed:

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Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror



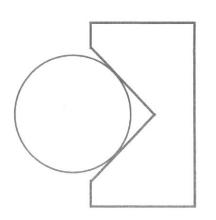
Interferometer Performance:

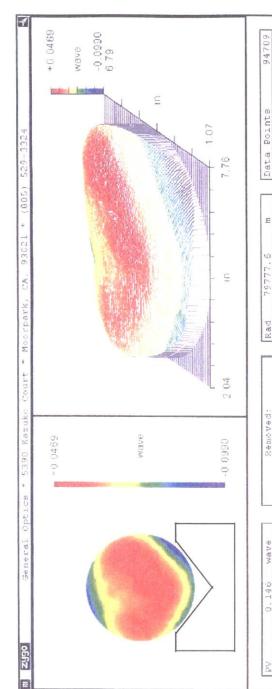
- pv 0.146 waves $(\lambda/7)$
- rms0.022 waves (\(\lambda/45\)
- waves PWr

-0.052

Measurement Orientation:

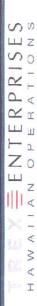
- Vertical (V-Block support)
- V-Block oriented in norma configuration as viewed ir interferograms.
 - Rotated again from previous position.





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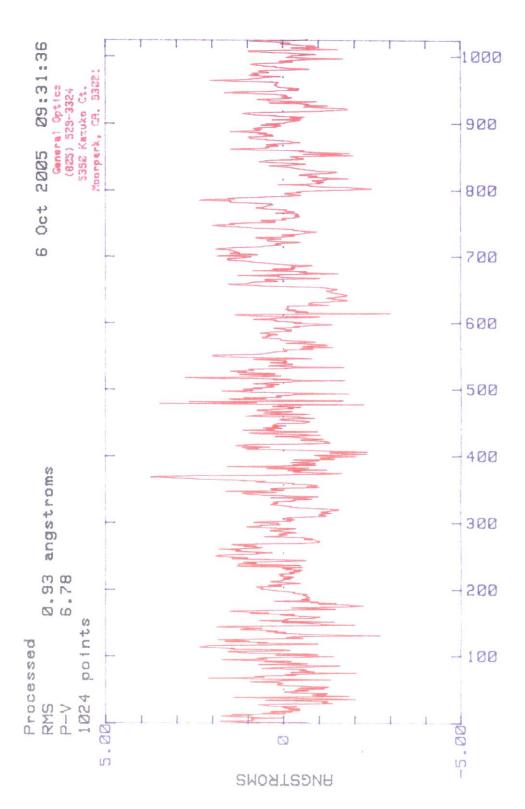
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Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SIC Plano Mirror Surface Roughness via Zygo



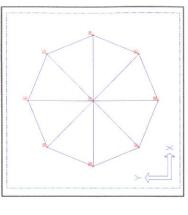




Chemical Vapor Composite Silicon Carbide for Space Telescope 150mm CVC SiC Plano Mirror Modal Analysis

Test was perform via classical ping test protocol.

- Foam bed used to simulate free state mode.
- Tiny hammer accelerometer & response accelerometer.
- Ping responses were collected from nine (9) points depicted in schematic (in figure at right).
- Software program transformed responses into wire plots of mode shapes as presented in earlier slides

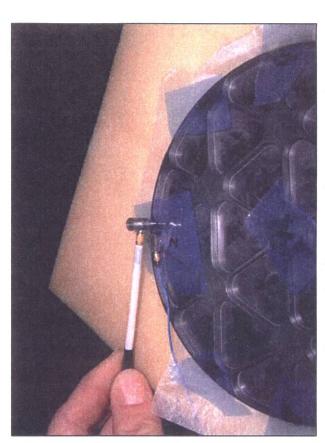


Wire Frame Schematic of Ping Test Points on Mirror

Comparison made to Finite Element Analysis Results



Test Setup Showing Foam Bed & Tiny Hammer Accelerometer



Hammer Accelerometer Shown as Tested

Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror

Modal Analysis Results

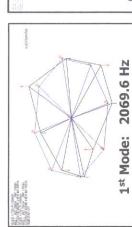
- A close correlation is established between the predicted modal values and the actual measured modal values
- Variance in higher modes can be attributed to:
- Difference between theory and reality.
- Constraint conditions in FEA model can not exactly duplicate actual constraint system as tested (foam bed).

Mode	1st	2nd	3rd	4th
Hz	2172.3	2172.5	3463.1	5464.1
Mode	1st	2nd	3rd	4th
	Hz	Hz 2172.3	Hz 2172.3 2172.5	Hz 2172.3 2172.5 3463.1

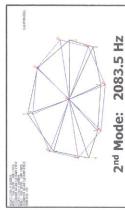
2069.6 2083.5 3343.8 4646.9 H Sured



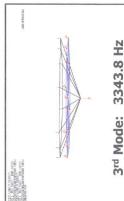
Predicted



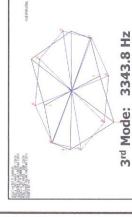














Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror Water Jet Cutting of CVC SiC

- Development of water jet cutting and milling process have proven to be feasibility for fabrication:
- Demonstrated Water Jet Cutting and Piercing Processes:



Water Jet Cutting Through 1.3" of CVC SiC Material



Initial Water Jet Piercing Through .5" of CVC SiC Material



Water Jet Piercing Through 1.3" of CVC SiC Material

Chemical Vapor Composite Silicon Carbide for Space Telescopes 50mm CVC SiC Plano Mirror Water Jet Milling of CVC SiC

5 Axis water jet milling capability has been established:

- Demonstrated water jet milling process:
- Current process produces punch through of 1.3" thick CVC SiC material in 40 seconds
- Cutting rates of over 1 linear inch per minute on 1.3" material have been demonstrated
- Milling rates of .010" per pass have been demonstrated.

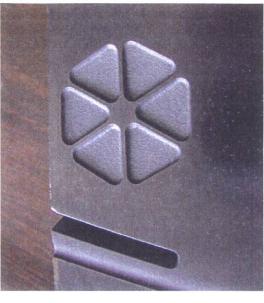


Water Jet Milling Simple Masking Setup



Water Milling of 25mm by 25mm Square by 4mm Deep Pocket in CVC SiC

Material



Water Milling of Isogrid for lightweighting of CVC SiC

- CVC Silicon Carbide is an ideal optical material, with high specific stiffness, superior thermal stability, polishability and low residual stress.
- 15cm plano CVC SiC mirror with excellent stiffness, surface figure and surface roughness has been demonstrated.
- Experimental and theoretical modal analysis show that CVC SiC components can be readily designed & modeled.
- Trex is proceeding with 750mm aperture mirror fabrication, to be completed in 2007.

